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A Collaborative, Iterative Approach to Transferring Modeling Technology to Land Managers

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3.1. INTRODUCTION

Land managers have come to realize that achieving many natural resource management goals requires a consideration of landscape-level patterns and processes (Boutin and Hebert 2002). A landscape perspective is necessary because many ecological processes operate at landscape scales (Turner 1989). For example, although silvicultural techniques applied at the stand level can be used to manipulate species composition and growth form, there are landscape-level processes (e.g., wind, fire, insect outbreaks) that also have significant effects on these stand characteristics (Liu and Ashton 2004). In a reciprocal way, landscape patterns also determine the likelihood of insect and disease outbreaks (Sturtevant et al. 2004a), fire ignition and spread (Hargrove et al. 2000), browsing by deer (Alverson et al. 1988), the influx of invasive species (With 2002), and pollution (Weathers et al. 2001). Each of these landscape-level ecological processes can influence the achievement of local-scale management objectives. Unfortunately, these multiscale processes sometimes interact in complex ways that are difficult to predict (Turner et al. 1994). Land managers therefore depend on sophisticated technology to predict the consequences of proposed management actions.

Public land-management agencies are particularly well positioned to implement landscape-level management because of the size of the land base under their jurisdiction. However, the complexities of ecological phenomena across scales and of the relationships among ecological processes are particularly daunting given the public's low tolerance for management mistakes (Teich et al. 2004). Therefore, public land-management agencies require analytical and prediction tools for modeling landscape processes and evaluating strategic management options in the context of changing management environments. These modeling tools must adequately represent the ecological system and the alternative management options. The representation of the ecological system must fully account for the interactions among all relevant ecological processes and management activities. For example, the management of fire risk can involve reducing the fuel loads in forest stands (either by manual removal of biomass or by prescribed burning), manipulating forest composition to encourage less-flammable species, manipulating the spatial pattern of the landscape mosaic to reduce the likelihood of fire spread, or taking action to control ignitions (e.g., road closures, campfire prohibitions). However, these actions may also affect forest succession, or the likelihood of insect pest outbreaks or catastrophic blowdowns, all of which affect the risk of fire (Fleming et al. 2002). Models that allow an assessment of fire risk under various alternative management options while accounting for these potential interactions should result in better decisions than when stand-level or overly simplistic models are the only source of support.

A variety of landscape-level analytical and projection models have been developed for various research and management purposes (Baker 1989; Sklar and Costanza 1991). In some cases, these models can be used to directly answer specific management questions and support decisions. In other cases, new models must be developed to provide specific information that is lacking from other models. Transferring these models or the information they generate from the developers to

the managers who will use these resources is usually difficult. In this chapter, we explore the reasons for this difficulty, and outline a collaborative, iterative approach to the transfer of modeling technology. We describe two case studies that illustrate the approach for specific management problems. We conclude by discussing the merits of the approach and the lessons learned through the case studies.

3.2. CONCEPTUAL FRAMEWORK OF THE TECHNOLOGY TRANSFER PROCESS

Technology transfer has often been approached as a marketing problem. Researchers view the technology they have developed as a product that they must “sell” to potential users, who are often referred to as “customers” or “clients.” This paradigm sets up a buyer–seller mentality that can hinder the successful adoption of complex technology by managers. We believe that the transfer of complex decision-support models presents at least seven formidable difficulties:

- Teaching managers or their support staff to run modeling software requires formal training and technical support. This is not unlike the process of learning any new software, but in addition, it requires an explanation of basic modeling concepts.
- Proper application of models by managers requires that they understand in some detail the assumptions behind the models and the limitations of the results. There is no small danger that inappropriate conclusions can be drawn should users of the models misunderstand the key underlying assumptions.
- Managers must learn how to interpret a model’s results to provide defensible support for their decisions.
- Managers must precisely explain to researchers the decisions they must make and the information or knowledge required to make those decisions. Such an understanding will help researchers to judge whether the model can in fact produce the information that is needed.
- Political, funding, or logistical limitations may constrain management options. These issues may not be apparent to researchers, so managers must identify them; researchers could also interview the managers to identify any relevant constraints.
- Researchers may be unfamiliar with the specific land base that is being managed, and may therefore be poorly equipped to accurately model the ecological or management dynamics.
- Managers and researchers may have different understandings of uncertainty and of the risks associated with that uncertainty. A shared understanding of the role of uncertainty in the decisionmaking process is critical.

A common thread among these difficulties is the necessity for substantive communication and partnership between researchers and managers.

To resolve these difficulties, we adopted a collaborative, iterative approach for technology transfer (Ahern 2002, Fall et al. 2001). The approach is *collaborative* because it assembles a triad of researchers, management planners, and local resource experts. It is *iterative* because communication among the triad partners must occur repeatedly, so that the application of the tool can be refined with each iteration. Our approach fosters a “community of practice” in which people build understanding together in a social, physical, and temporal setting (Allee 1997, p. 219).

The conceptual framework for our collaborative, iterative approach to technology transfer is best represented as a triangular interaction among researchers, management planners and decisionmakers, and local resource experts (Figure 3.1). The interaction takes the form of iterative communication (the arrows in Figure 3.1), and the focus of the communication is on application of the modeling technology to support a particular management decision. Thus, the modeling tools serve as a common framework that lets all parties conceptualize and formalize (i.e., model) the management problem. The end result is a more defensible decision and a transfer of modeling technology from a research environment to a management environment. This approach also fosters the development of a shared vision of the model’s requirements and the decision process to be supported, of the data requirements, of the interactions among ecological and human processes, of the model’s capabilities and assumptions, and of how to appropriately interpret the model’s outputs.

The collaborative nature of the process is important because each partner provides expertise that is critical to successful technology transfer. The researchers understand the feasibilities of applying existing models or building new models, know the assumptions that underlie a model, are familiar with the algorithms that drive a model, know how to estimate the model’s parameters and develop the input data, provide the technical expertise to run a model, and guide interpretation of the

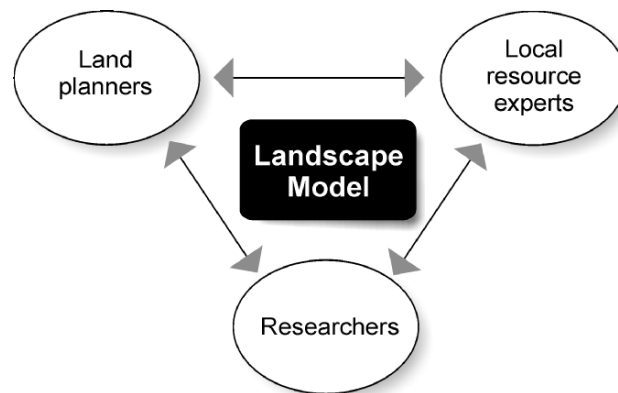


Figure 3.1. A conceptual framework for the collaborative, iterative approach to technology transfer. A triad of decisionmakers, researchers, and local experts collaborate to implement modeling technology and provide decision support. The arrows represent iterative communication.

model's results. Models are not a mysterious black box to the researchers who developed them, and this knowledge helps them to make the models more transparent to the other partners, giving them greater confidence in the output. The management planners understand the management decision that must be made, and can readily identify the information gaps that hamper their ability to make defensible decisions. They also can identify the bounds of politically or logistically feasible alternatives. Without such input, researchers are likely to develop elegant and sophisticated answers to irrelevant questions. The local resource experts enable the model application to reflect the best current knowledge about the system under study. They help the researchers to estimate realistic values of model parameters for the local ecosystems. They can readily identify model behaviors that incorrectly simulate the local reality and assist the planners to develop ecologically feasible management options. A two-way collaboration that only includes the researchers and planners is more likely to result in biologically indefensible results.

The collaborative interaction begins with a meeting of all three groups. The initial iteration focuses on sharing of information about the management decision to be made, the alternatives that will be compared, data availability, and the modeling tool to be applied. Resource experts inject biological reality into the discussion. Following this meeting, the researchers design the modeling protocols, work with the resource experts to estimate the model parameters, oversee the generation of input data, and perform the initial simulation runs. During this time, the researchers contact resource experts to clarify and refine the initial parameters. The second iteration brings all parties together again to review the initial model outputs. The resource experts assess whether the model's behavior is consistent with their understanding of the ecological system. The planners assess whether the information generated by the model is what they need to make a decision, and if not, work with the researchers to refine the modeling objectives. The researchers communicate any needs for better parameter estimates or additional information about management alternatives. A second round of simulations is then conducted based on the improved understanding of the management problem. The process is repeated until all parties are satisfied that the model is producing the information required to make the decision. Collaboration and iteration produce several important outcomes:

- The model results are of greater quality and relevance to the decisionmaker.
- Managers learn to use a new technology.
- Researchers learn about management problems and the constraints that managers face.
- Resource experts come to better appreciate the interactions among many resources and the realities of multiple-use planning.

The collaborative nature of the approach provides the synergy required for effective technology transfer.

To illustrate the application and utility of the collaborative, iterative approach to technology transfer, we will describe two case studies in which modeling technologies

were successfully transferred from a research and development environment to operational use, to meet a management decision-support need. The second case study is a technology-transfer effort in progress. The first used the SELES modeling language to construct a new model that would support a complex and controversial land-use planning process. The second used the LANDIS model to predict how patterns of human settlement and forest management in the Nicolet National Forest (Wisconsin, USA) might intersect to influence fire risk. Before presenting the case studies, we have provided a brief orientation to the modeling technologies used and the philosophy behind their development to describe the basic principles of the underlying science.

3.3. DESCRIPTION OF THE MODELING TECHNOLOGY TO BE TRANSFERRED

3.3.1. SELES

SELES (the Spatially Explicit Landscape Event Simulator) is a model-building and simulation environment that attempts to strike a balance between the flexibility of a programming language that can be used to construct novel models and the ease of applying and parameterizing (estimating the parameters for) existing models (Fall and Fall 2001). Its foundation is a declarative language that lets its users focus on defining the specific needs of landscape modeling and analysis rather than a strictly procedural language that focuses on the details of computer program execution. By providing a language closely adapted to landscape ecology and spatiotemporal modeling, it allows relatively rapid and transparent development of models. For example, models can be written in the form of text files that are loaded directly into SELES rather than imposing the complexity of a conventional software development environment. The underlying assumptions are therefore explicit and not hidden within a black-box program that cannot be examined by anyone other than the programmer, and are not inseparably intertwined with the complicated programming code that performs the actual simulation. SELES models have been successfully applied to support landscape-level forestry decision processes in land-use planning (Fall et al. 2004a; Morgan et al. 2002), the management of natural disturbance (Fall et al. 2004b), and parks planning (Manseau et al. 2002).

The model-development process can be conceptualized using the analogy of car production (Figure 3.2). The overall objectives for a new car (by analogy, the landscape model) are set by marketers and clients (stakeholders). The design is created by engineers (modelers and resource experts) who understand automobile (modeling) capabilities, and the constraints and opportunities imposed by materials and aerodynamics (system knowledge and feasibility thresholds). They combine experience and knowledge with design objectives to create a blueprint (a conceptual model). It is important to note that the designers do not actually build the car, so they do not need to know the details of the implementation tools and technology, but they do need to understand the potential capabilities.

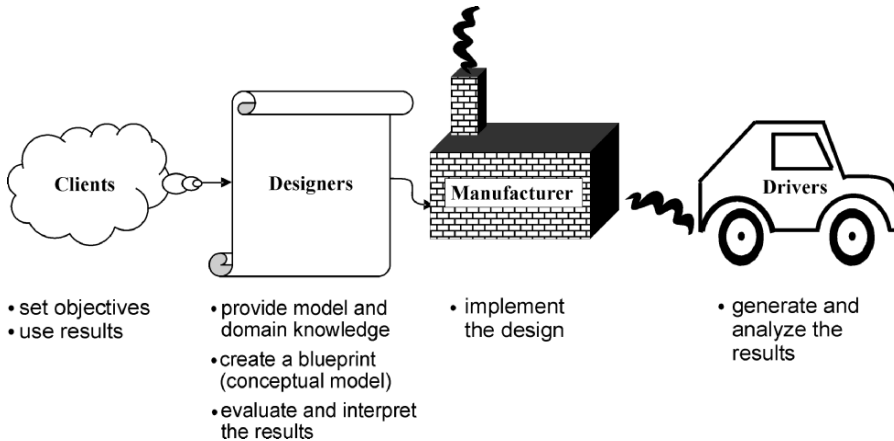


Figure 3.2. The various people involved in the modeling process, starting with those who set overall project goals and ending with those who analyze the model's outputs. The drivers are linked iteratively with the clients to communicate results and ensure that the desired outcomes are achieved.

The people who construct the car (build the model) must understand the operation of the factory machines and input resources (model-building tools and input data). They must be capable of understanding a design blueprint and implementing it (starting with prototypes), but do not necessarily need to be able to create designs. They must be able to test the car (the model) by means of test drives to ensure that its implementation matches the blueprint (preliminary model verification). This leads to the first level of iteration, which is performed entirely within the factory by the manufacturer (the modeling research team). Given a product that matches its design specifications, further testing is then required to assess how well its performance matches the design objectives. This may lead to a second level of iteration, indicated by the feedback arrow between designers and developers in Figure 3.1, in which the designers refine any of the blueprints that require updated implementations.

Given a car that matches its specifications (a verified model), a driver (the user of the model) can take the car for a ride (conduct a simulation). The driver does not need to understand the details of the blueprint or the manufacturing process. However, a user guide describing the control features and the consequences of manipulation of the controls is essential, as is an appropriate road map and destination (directions for what scenarios to assess with the model). Some basic knowledge of mechanics (understanding of basic information on modeling) can help the driver (the model user) make minor repairs or modifications and customize the vehicle (the model) in order to make the fullest use of the product and to reduce reliance on the factory workers. Understanding the assumptions that govern the use of the car (the model), such as the fact that the car is not designed to operate in a body of water, is also necessary. For something as familiar as a car, this knowledge is implicit, but

for modeling, the knowledge is more abstract and must be taught to the model's users. Dials and other feedback features (progress indicators in the modeling software) provide indicators during a drive and a travel log (model output indicators) provides a long-term record.

Assessing whether the car meets its original objectives will likely require a number of drives under different conditions. Summaries of the travel logs can be analyzed by designers and presented to those who defined the original objectives (stakeholders), completing the third level of iteration.

The key features of this analogy that are relevant to the development of a model are:

- The process is inherently collaborative, with multiple levels of feedback and iteration. Products at one stage are used to refine the objectives (higher-level specifications) for subsequent stages. The feedback emerges through communication between all parties during all stages to ensure that objectives are met and that later stages encapsulate the results of earlier stages.
- No one person performs all modeling tasks. A range of modeling expertise is required for success, particularly for model design (abstraction of reality), model implementation and testing, and model utilization and analysis.
- The process involves multiple levels of abstraction, and people at one level in the process only need to fully understand the aspects of the overall system that are relevant to their level. This helps to reduce the scope of the problems to be addressed during any given stage, and minimizes the level of perceived complexity at any stage.

Modeling tools can be placed along a spectrum from traditional procedural programming languages to fully constructed models (Fall and Fall 2001). Building models directly by programming is akin to constructing a new car without a specialized factory, using generic hardware and tools. On the other hand, using a prebuilt model is akin to using the same car for all types of transportation needs (i.e., fitting the question to the model rather than vice versa). SELES fills a niche by providing a “model-building factory” that facilitates the production of customized models that suit the user's objectives.

3.3.2. LANDIS

LANDIS is a landscape model that simulates spatial forest dynamics, including forest succession, seed dispersal, species establishment, various disturbances, and the interactions among these factors (Gustafson et al. 2000; Mladenoff and He 1999). LANDIS was developed as a research tool to simulate the reciprocal effects of disturbance processes (i.e., fire, wind, vegetation management, insect outbreaks) on patterns of forest vegetation and vice versa across landscapes up to 1 million ha in size and long time scales (50 to 1000 years). Our purpose here is not to describe LANDIS in great detail, but rather to demonstrate the model's power and the complexity of parameterizing and using the model.

LANDIS (v 4.0) uses a raster-based map (i.e., a grid), in which each cell contains information on the presence or absence of a tree species and the 10-year age cohort of that species, but no information about the number or size of the individual stems. Forest succession processes are simulated based on the relative ages of the species found in each cell and on the vital attributes of the species (e.g., shade tolerance, probability of establishment within each land type, longevity, seed dispersal distance). Disturbances remove certain age classes, and the number and characteristics of these classes depend on the severity of the disturbance, which in turn is determined by the characteristics of each cell and in some cases by the characteristics of nearby cells. The number of occurrences and spatial extent of a disturbance are determined by a number of parameters that typically vary as a function of land type. For example, the fire regime for a given land type is defined by the mean size of fires, fuel accumulation rate, and fire-return interval, which is defined as the average number of years required to burn an area equal to the area of the land type on the landscape. Forest management activities are specified by a spatial component (algorithms and spatial zones that determine the order in which stands are selected for treatment), a temporal component that specifies the timing of treatments, and a removal component that specifies which age classes are removed by the treatment. Readers interested in more details of the model should consult Gustafson et al. (2000), He et al. (1999a,b, 2004), He and Mladenoff (1999), Mladenoff and He (1999), Sturtevant et al. (2004a), and Yang et al. (2004).

A powerful attribute of this modeling approach is the feedback between disturbance and species response. For example, windthrow events may alter the species composition relative to sites without windthrow, and will contribute to fuel accumulation on a site, increasing the severity of subsequent fire events. The forest harvest module of LANDIS provides the ability to simulate specific and complex management alternatives, including timber extraction, fuel reduction treatments, and prescribed fires. The interaction of such treatments with natural disturbances and with the dynamics of forest succession produces powerful insights into the complex cumulative effects of specific proposed actions. For example, LANDIS simulations have shown an interaction between ecological land type (defined by land form, soils, and climate), management prescriptions, and initial conditions, and have predicted a highly variable risk of canopy fire in northern Wisconsin, USA (Gustafson et al. 2004; Sturtevant et al. 2004b).

Although LANDIS is a powerful projection tool, it is also quite complicated to use. The model requires input maps that specify the initial forest conditions for each cell of the grid. Preparation of these maps requires sophisticated statistical estimation and mapping techniques (He and Mladenoff 1999). Depending on the species, at least eight vital attributes must be parameterized for each species, and scaling methods are typically used to estimate species establishment coefficients for each land type (He et al. 1999b). At least 15 parameters are required to define the statistical distributions of natural disturbance regimes and fuel accumulation rates for each land type. A new fuel module (He et al. 2004) requires three times as many parameters as previous versions of the model. The sheer volume of the model

outputs and the computational demands of the simulations require a fairly powerful desktop computer. For these reasons, LANDIS applications are somewhat intimidating for most land managers.

3.4. CASE STUDY 1: THE MORICE LAND AND RESOURCE MANAGEMENT PLAN

The northwestern interior area of British Columbia, Canada, is rich in biodiversity and in natural resource values (e.g., forestry, mining, tourism), and its landscape has a complex and varied geography (e.g., plateaus, fiordlike lakes, glaciated mountains). Different value systems (e.g., conservation versus resource development) have created conflicting perspectives on the best land uses. To help resolve conflicts and guide future land use in this area, the provincial government initiated a multistakeholder land-use planning process to develop the Morice Land and Resource Management Plan, which covers an area of approximately 1.5 million ha. The goal of the planning process was to reach agreement on land-use zoning (e.g., protected areas versus intensive or general management) and objectives (e.g., a sustainable and viable forestry sector and conservation of threatened species).

Assessing the risks to ecological values and the economic opportunities in this area required an analysis of complex spatial and temporal interactions among key landscape processes and states. A government technical team was formed to provide decision support to the Land and Resource Management Plan planning group (stakeholder representatives) by capturing knowledge and distributing information to support the planning process. These groups were both part of the “land planners” category in the conceptual framework shown in Figure 3.1. This decision-support system combined projections of a variety of processes and indicators to create an integrated landscape-analysis system, and at its core was a spatial landscape dynamics model, the Morice Landscape Model (MLM). The MLM was constructed using the collaborative, iterative landscape-analysis framework (Fall et al. 2001) by adapting models from prior projects (e.g., Morgan et al. 2002), and was implemented using the SELES (Fall and Fall 2001) modeling tool. A core modeling team worked with local resource experts and the government technical team, who in turn worked with the Land and Resource Management Plan planning group to communicate the implications of alternative scenarios and project the impacts of landscape change on timber supply, biodiversity, and species of concern.

The critical processes that were modeled included forest growth, natural disturbance, harvesting, and road construction. Resource experts conducted postsimulation interpretation and analysis of the MLM results to determine the effects of each scenario on species representative of healthy ecosystems, including the grizzly bear (*Ursus horribilis*), mountain goat (*Oreamnos americanus*), northern goshawk (*Accipiter gentilis*), and woodland caribou (*Rangifer tarandus caribou*). Because the MLM simulates both economic and ecological processes, it was possible to identify trade-offs between economic activities and ecological risk, and to define quantitative

boundaries to the social trade-offs among the values for this landscape that were emphasized by the various stakeholders.

For successful technology transfer, it was critical for participants to recognize that the MLM was embedded in a human network of resource experts, special interest groups, stakeholders, and decisionmakers. The landscape model provided a tool that allowed experts to explore the decision space and to assess the existing and potential management regimes by evaluating indicators of the ecosystem's state, conducting experiments, and defining the bounds of the problem (i.e., identifying the feasibility limits for solutions to the problem). Resource experts gained an understanding of how the landscape, wildlife, and vegetation would change given certain human interventions and natural processes. Through the government technical team, this information was then distilled and communicated to the Land and Resource Management Plan planning group (which comprised people with and without technical expertise) in a form that helped them converge on a final plan. The critical point was that the transfer of analytical and technological information from the model occurred via the interaction between the resource experts and the planning group, and it was this human component of the system that explained the knowledge and information derived from the model to the decisionmakers. Hence, during the transfer process, information was transformed from highly quantitative and detailed data (e.g., geospatial inputs, yield tables, constraints, zones) into more qualitative and general data regarding ecological and economic risks.

3.4.1. Overview of the Morice Landscape Model

This section briefly describes the main concepts and assumptions underlying the MLM. The definition of this model using SELES consists of a linked set of two types of submodel: submodels of landscape change and submodels that calculate indicators for timber supply and ecological risk. The inputs consisted of digital raster maps at a 1-ha resolution that described the spatial aspects of the land base (e.g., elevation, forest cover, management units, roads), as well as tables (e.g., volume yield tables, harvest flow) and parameters (e.g., harvest level) containing information that is not tied to a specific piece of land. Time is modeled in 1-year or 10-year steps, with a time horizon of 250 to 400 years.

Outputs included text files that recorded various aspects of the condition of the land base (e.g., the growing stock or age-class distribution) and spatial time series (e.g., stand ages). The MLM simulates specified processes by projecting initial landscape conditions forward through time using stochastic techniques (i.e., by using the probabilities of change from one state to another). However, it does not determine optimal solutions. Thus, each model run may produce different results and the model must be run several times to determine averages and ranges for each scenario being modeled. The model's users must then compare these results with those of other simulations based on different parameters. The overall model design is shown in Figure 3.3, in which landscape states are shown in the middle, process submodels are shown as ovals, and output files are shown as gray cylinders. An arrow emanating from a

by looking up the corresponding value in a yield table, and was summarized to obtain indicators of growing stock.

Natural disturbance model. Stand-replacing natural disturbance was modeled using disturbance rates and patch-size distributions for the area's biogeoclimatic zones based on an analysis of historic disturbance levels for the area (Stevenson 2002). This top-down, empirical approach captures all agents of stand-replacing natural disturbance, and was used to help ascertain appropriate targets for ecosystem-based management objectives. The disturbance agents were primarily fire, mountain pine beetle (*Dendroctonus ponderosae* Hopkins), spruce beetle (*Dendroctonus rufipennis* Kirby), and western balsam bark beetle (*Dryocoetes confusus* Swain).

Harvesting model. The harvesting submodel was adapted from a prior spatial timber-supply model constructed in SELES that captured the same management regimes, assumptions, and data requirements as the aspatial timber supply model Forest Service Simulator (FSSIM) used for timber supply analysis by the British Columbia Ministry of Forests (BCMOF 2002). The submodel was extended to include spatial constraints such as spatial blocks (i.e., barriers to a process), road access, and block adjacency. A scenario to capture current forest management policy was calibrated against an aspatial analysis done as part of the province's timber supply review process using FSSIM (BCMOF 2002). This calibration step was key to the acceptance of MLM by foresters who were unsure of the model's ability to perform a realistic timber supply analysis.

In general, harvest blocks were limited to eligible land, such as accessible stands older than the minimum harvest age. The start points for cut blocks were selected from among the eligible sites based on stand age (with preference increasing as stands aged beyond the harvestable age); the blocks then grew to encompass neighboring cells until a preselected block size was reached. Harvest effects include extraction of merchantable volume, resetting of stand age, constructing roads (for sites accessible from the ground), and updating of tracking variables (e.g., the annual area harvested). Blocks are simulated sequentially within a period until the harvest target for the period is met.

Road access. The logging submodel explicitly connects cut blocks to the main road network by identifying straight-line spur roads to the nearest mapped road or previous spur road. If a proposed mapped road segment is connected to a spur, it is activated. This method of modeling road development accounts for feedback between current limitations on access and the road building required to permit harvesting of certain areas, and thereby reduces access limitations over time.

3.4.3. Indicator Models

Indicator models were designed by the researchers to summarize and produce customized information used by the resource experts to assess timber and ecological values. As such, they were developed in close collaboration with the resource experts, so that each expert shared ownership of that portion of the MLM. This improved buy-in from the wide variety of experts, and increased their confidence in subsequent analyses and presentations to the Land and Resource Management Plan planning group.

3.4.4. Outcomes

The Morice Land and Resource Management Plan planning group reached consensus early in 2004, and the final agreement was passed to the provincial government's cabinet ministers, who are the top-level stewards of public land in British Columbia. Further application of the MLM was used to help support a socioeconomic impact assessment by government experts, who in turn advised the politicians. In the spring of 2004, the plan was accepted and the implementation stage began. Implementation involved additional negotiations with First Nations, changes in legislation, the initiation of management plans for new zones, operational restructuring for affected people and industries, and the design of monitoring systems to assess the plan's objectives as implementation unfolded. The reliance on the MLM in the final political stage of the process demonstrates how this approach facilitated the transfer of analytical results from an exploratory stage by the planning group (which focused on the relative costs and benefits of alternative plans) to final analysis (which focused on the absolute costs and benefits of the final plan).

3.4.5. Obstacles and Lessons Learned

The importance of transparency and adequate communication in this process cannot be overstated. It was essential to walk interested members of the government technical team through the main model assumptions. This was a challenging step, but was necessary to ensure that the planning group would have confidence in the results presented by the resource experts. A second challenge related to managing expectations and maximizing shared learning of capabilities of the system and the model. On the one hand, the researchers had to strive to provide the flexible, customized information required to support the planning process, and on the other hand it was critical to communicate clearly about items that were not feasible to include (e.g., due to a lack of time or data). A third challenge related to timing: preliminary analysis of the preplan management and the final plan analysis had to be quite detailed, but neither was constrained by time. However, analysis of the trade-offs in intermediate versions of the plan, especially toward the end of the planning negotiations, had to be done very quickly (i.e., within days, and sometimes hours) to provide information in a relevant time frame. When deadlines could not be met, the information could not be used.

3.5. CASE STUDY 2: MANAGING FIRE RISK IN THE WILDLAND-URBAN INTERFACE

Mitigating the risk of wildfire has become an urgent issue for the managers of many North American forests (Finney and Cohen 2002). Wildfire risk is a consequence of complex interactions among natural disturbance regimes, vegetation management activities (e.g., timber management, fuel reduction), and the increased presence of

people in forested landscapes. Portions of the Lakewood Unit of the Chequamegon-Nicolet National Forest (Wisconsin, USA) feature both highly flammable jack pine (*Pinus banksiana* Lamb.) and red pine (*Pinus resinosa* Ait.) and a relatively high proportion of privately owned land within the forest that have experienced rapid exurban development in recent decades, a trend that is expected to continue. Recent research by Sturtevant and Cleland (2003) indicates that the probability of forest fire ignitions in Wisconsin is primarily a function of housing density, whereas the probability of large fires depends more on the ecosystem properties that control fire spread, such as soil water retention and the flammability of the vegetation. Fire management officers and land planners were seeking long-term guidance on forest management strategies to mitigate the risk of fire damage to timber and private property in the Lakewood Unit, a fire-prone, mixed-ownership region of the National Forest. The critical issue was the rapid increase in exurban development intermixed with fire-prone federal lands.

Two of us (Sturtevant and Gustafson) began collaborating with fire-management officers responsible for the Chequamegon-Nicolet National Forest. Our purpose was to describe the available tools for landscape simulation and identify critical issues that might be addressed with such tools. We began the collaborative, iterative process with a simple discussion between ourselves and decisionmakers for the National Forest. The managers explained the management situation described earlier in this section, and expressed their need for a scientific basis on which to generate and evaluate specific management actions they could take to reduce the risk of wildfire and protect the human communities within the wildland-urban interface. We described several modeling tools that could meet such a need, and outlined the pros and cons of each. After some discussion, the team decided that a combination of tools would be required. LANDIS would estimate fire risk by accounting for the interactions among vegetation-management treatments, forest succession, natural disturbance, and human-caused ignitions. However, LANDIS cannot currently predict the expansion of human populations through time. This ability was deemed critical to meet the future decision-support needs of the managers, but was deferred to a later phase of the project. In the meantime, we used the current extent of exurban development.

We spent the following months preparing for the first workshop, in which we would begin the collaborative technology transfer. The original participants in the discussion collectively identified additional key participants, including land managers and planners from the National Forest (the Fire Management Officer, District Ranger, and District Project Coordinator), resource experts (two silviculturists and the District Fire Management Officer), and researchers familiar with the modeling tools (two LANDIS developers, two LANDIS users, and a human demographer). Finally, we acquired the input data needed to conduct prototype LANDIS simulations, including data on current forest conditions, current harvest practices, the region's fire regime, and the current pattern of exurban development.

There were four main objectives of the first workshop. First, we needed to clearly articulate the objective of the collaboration based on input from all participants. In this case, our objective was to investigate the fire risk associated with

various forest-management alternatives and their interaction with exurban development within the Lakewood Unit. Second, the researchers explained the technology (i.e., LANDIS) that would be applied to meet the stated objective. Third, the researchers presented prototype LANDIS simulations, and used the results to spark discussions with the resource experts on several areas of uncertainty in the prototype. For example, we discussed the relevant and important tree species in this ecosystem, the role of wetlands in landscape-scale fire behavior, the critical drivers responsible for fire spread, local fire-suppression tactics (e.g., the use of roads as fire breaks), and the forest composition on private land (i.e., where data were lacking). Finally, the land planners provided guidance on how to implement the current forest management plan within LANDIS, and discussed potential strategies for mitigating fire risk.

The research team spent several months incorporating the recommendations and data resources provided by the broader group into a LANDIS simulation run. During this time, we consulted regularly with the local resource experts for clarification and refinement of the simulation parameters. Our efforts at this stage were devoted to developing realistic LANDIS simulations. Simulation runs projected the forest's composition, spatial pattern of fuels, and fire risk in the Lakewood Unit over the next 250 years based on the current forest management plan and on the assumption of no additional exurban development.

The next iteration of our collaboration was conducted in a second workshop with the entire group and the results of the initial simulations were presented. The resource experts and planners then provided feedback on the realism and utility of the model results. Our demonstration was followed by a brainstorming session to develop several novel, spatially explicit fire-mitigation scenarios. The alternatives were constrained by the current Land and Resource Management Plan, which established the broad management directions for the National Forest but allowed considerable latitude in the implementation tactics. For example, strategic conversion of existing coniferous stands and establishment of new coniferous stands were both designed to minimize the adjacency between human ignition sources and coniferous fuels and to reduce the overall risk of wildfire spread across the landscape. Because the input maps and parameter files were already in place, we could quickly implement the scenarios for mitigating fire risk.

The effectiveness of these strategies was evaluated during the third iteration of the process to gain insight into the effects of specific elements of the risk-mitigation strategies. This allowed the managers to identify the most effective strategy for further evaluation and refinement.

3.5.1. Outcomes

One important outcome of the process was that each group in the triad (Figure 3.1) gained valuable insights from the other two groups, and this helped them to contribute more usefully to the final decision. Another valuable outcome was that the modeling technology was used to support a critical management decision.

But the most important outcome is that the team will continue to develop a sound fire and fuel mitigation strategy for the Lakewood Unit. The temporal and spatial distribution of fire risk predicted by the LANDIS model helped the team to develop novel ideas for mitigating fire risk that might not have been apparent without the model projections for reference. The LANDIS technology thus allowed the team to evaluate the effectiveness of alternative strategies both spatially and quantitatively. The strategy that is eventually adopted is expected to be superior to one that would have been developed without the decision support made possible by the collaborative, iterative approach to transferring LANDIS technology.

3.5.2. Obstacles and Lessons Learned

Our collaborative approach to technology transfer required effective communication among the three knowledge groups (Figure 3.1), using the landscape model as a means of focusing critical discussions and a series of workshops as the primary means of information exchange. Well-organized workshops that foster communication were therefore a key to our success. A potential obstacle in reaching that goal lies in finding the appropriate balance between general discussions and examinations of the specific details of the model. Discussion topics should be organized around key modeling assumptions or uncertainties, but should remain sufficiently broad to encourage real feedback from all three knowledge groups. In turn, these general discussions must be followed by more specific question-and-answer periods that will be used to actually parameterize the model. Nonetheless, the tendency of scientists organizing a technology-transfer workshop is to dwell exclusively on the model details (i.e., the technology), an approach that can effectively discourage more fundamental input from the other two knowledge groups. In our experience, the encouragement of more general discussions allows participants to identify areas of uncertainty that are apparent only to those with more direct knowledge of the system to be modeled.

A second obstacle that we encountered was the difficulty in clearly communicating among the different knowledge groups, each of which had its own terminology and frame of reference. For example, the fuel module of LANDIS 4.0 was designed to incorporate local expert opinion so as to guide the interaction between fire and fuel patterns (He et al. 2004). However, because local fire experts did not participate in the development of the LANDIS fuel classes, we found it difficult to translate their expert experience into actual parameters. In the end, we provided output comparisons between LANDIS and the modeling tools the fire experts were already familiar with (i.e., BehavePlus, Andrews et al. 2003; FARSITE, Finney 1998), thereby effectively calibrating the LANDIS model to fit their experience. Though this effort took additional time, it both informed the researchers and improved the confidence of local experts in the output of the LANDIS model. Another method for ensuring effective communication among groups is to provide a brief synopsis following each workshop, and circulate it among the group participants for comment. This provides an opportunity to correct any misinterpretations of workshop discussions before they are incorporated in the model.

Because our simulations assumed a static human presence in the study landscape, the effects of future development were not incorporated into the predictions. The research team brainstormed solutions to the human component of the question, and identified an appropriate simulation tool (the “planning support system”) to fill this need. Planning support systems are integrated packages of analytical tools based on geographical information systems technology that perform three critical tasks: conducting an analysis of land suitability, projecting future land-use demand, and allocating the projected demand to suitable locations. Although these systems do not predict future conditions exactly, they do attempt to determine future conditions given certain policy choices and development assumptions. We have decided to use such a tool to provide the human development projections that will be incorporated in future LANDIS simulations.

3.6. COMPARISON OF THE CASE STUDIES

One of the clear differences between the two case studies lies in the development of a new model versus the use of an existing model. Technology transfer performed during the collaborative development of a new model offers two main advantages. First, all participants share intellectual ownership of the technology, and this increases their confidence in the model results. Second, developing a new model ensures that the tool fits both the available data and the specific questions that must be answered by the management application (Fall et al. 2001). In the second case study, much of the development time was devoted to transforming the available data into the inputs required by LANDIS. The choice between creating a new model and using an existing one thus depends on how well available models can address the question at hand, and on the time required to implement an existing model compared with creating a new one. Software tools such as SELES (for landscape models) and STELLA (Costanza et al. 1998; for stock and flow models, which represent a system as compartments or stocks of entities and fluxes or flows of matter or energy between stocks) are decreasing the time required to create new models, and are therefore conducive to the collaborative approach to technology transfer that is described in this chapter. Previously published models have the advantage of the additional scientific rigor that results from peer review. In the second case study, less energy was required to validate the successional dynamics of LANDIS because the model had been tested extensively in various temperate ecosystems around the world (Mladenoff 2004).

Although these case studies differed markedly in terms of the objectives of the decisions being supported, the ecology and disturbance regimes of the landscape under study, and the technology used for the decision-support model, a number of common themes relate directly to the iterative, collaborative process that we have proposed. One critical component of both case studies was the active participation of all knowledge groups in developing the landscape model (Case Study 1), parameterizing the landscape model (Case Study 2), and developing and evaluating

relevant scenarios (both case studies). Such active participation inspired confidence in the technology by transferring intellectual ownership from the researcher to the other two groups. Workshops and face-to-face discussions on various aspects of the problem (decision objectives, local knowledge, capabilities and limitations of the technology) facilitate participation. Note that it is not necessary that all aspects of the model be transparent to all participants in the process. Different resource experts can verify the assumptions for different aspects of the model, and can transfer their confidence in those assumptions to the rest of the participants. Such synergistic participation minimizes the time investment required from each member of the collective group. However, it does increase the time investment by the researcher in the technology-transfer process. Justification for this additional time investment comes from the increased future independence of the managers when they use the technology, and the increased knowledge gained from the other two groups that researchers can apply to future technology transfer.

In both case studies, once the analytic technology had been selected, discussions focused primarily on the conceptual model of the system and the information required as inputs for this model, because this is the level at which meaningful discussion among the three parties is possible. Too much focus on the tool draws attention away from the main objective, and may limit accessibility to the process for people who lack sufficient technical training. Both case studies demonstrated flexibility in how the collaborative, iterative approach was applied—it was not a recipe to be rigidly followed. Rather, the appropriate timing of workshops and levels of involvement by the various parties must emerge during the course of a project, thereby enhancing mutual learning and ensuring adequate levels of communication.

There is a risk that researchers may lose their objectivity by working so closely with members of the planning team. Also, the distinction between the local resource experts and the planning team may become blurred when members serve in both capacities. Care must be taken to avoid tweaking the model inputs and assumptions to fit some preconceived notion of the results. To ensure that the technology is not abused, the modeler must clearly document the model's assumptions and limitations, and the appropriate methods of interpreting the outputs. During technology transfer, these potential pitfalls imply that any project that applies complex systems models requires at least one person to fill the researcher's role and ensure that all participants are aware of the pitfalls and can respond appropriately.

3.7. CONCLUSIONS

Based on the experiences described in this chapter, we conclude that the collaborative, iterative approach to technology transfer provides several important benefits that are lacking in traditional buyer–seller approaches. First, the collaborative component encourages the establishment of long-term working relationships. This is important because it develops a mutual commitment to a successful outcome by fostering a shared vision and shared goals. It also allows a shift from a focus on

decisions as discrete events to a focus on decisions as a continuous process that fits within the context of adaptive management. The focus of all parties is on the outcomes rather than on the process of technology transfer. In contrast, the traditional buyer–seller relationship between researchers and managers has evolved into a marketing game in which the sale is more important to the researcher than the effectiveness of the management decisions (i.e., the pressure to report technology transfer may encourage researchers to focus on their self-interest). A collaborative approach serves to correct these perverse incentives and break down some of the walls that have separated managers and researchers by increasing the likelihood of a mutual success.

Second, the iterative component of the approach serves to progressively improve the quality and relevance of the model as a decision-support tool. Model parameters and inputs are improved by the reality checks provided by managers and resource experts during each iteration. Because the model and its results are described and discussed at some length as an integral part of the iterative process, the managers become increasingly educated about the technology, and the model becomes much less likely to be perceived as a mysterious black box. This inspires more confidence in and understanding of the results, thereby increasing their value for decision support. The extended interactions that result from this approach help all parties to learn and develop a more mature understanding of the overall picture. Each party is in effect providing on-the-job training for the others, and this training should enhance the effectiveness and efficiency of future partnerships with the same team or with new teams established for other purposes.

Third, in this approach, all parties have a vested interest in the success of the other parties. The approach is framed in terms of the outcome rather than in terms of technology transfer *per se*. When the outcome is achieved, all parties can claim success. Managers can then take advantage of the latest modeling technology to obtain sound and relevant support for their decisions. Their decisions will become more defensible, and they will be more likely to achieve their management objectives. Resource experts will provide critical input to the process, and will therefore have played a key role in shaping the management decision. Researchers will have successfully transferred their technology to a management environment, and know that their technology will make a difference “on the ground.”

The collaborative, iterative approach to technology transfer can be applied to any complex technology used to support natural-resource management decisions. The main feature of the approach is a sustained partnership that changes the technology-transfer paradigm from a buyer–seller mentality to an outcome-based model in which all parties can win. The approach is structured so that all parties achieve success when the outcome is achieved, and this provides adequate incentives to encourage meaningful collaboration. The approach itself is not complex, but it facilitates the transfer of complex technology by keeping those who understand those complexities attached to the technology. We believe that in many cases, this is the only way to achieve successful application of such technology to “on the ground” management decisions.

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